EMISSIONS FROM AN OVERHEATED ELECTRIC MOTOR WITH SLOT CELLS AND WINDING PHASES INSULATED WITH AN AROMATIC POLYAMIDE PAPER

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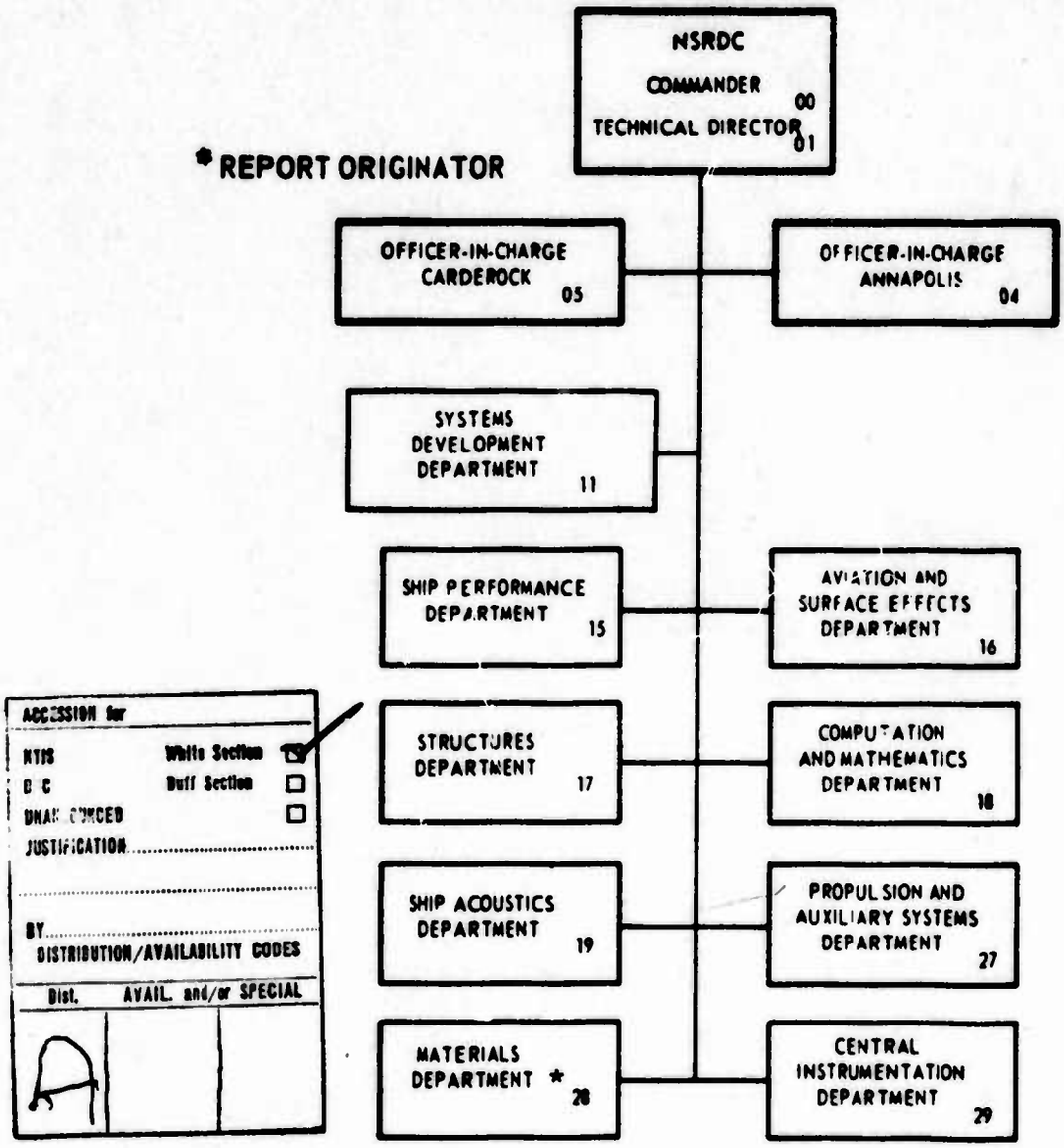

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A standard Navy 10-horsepower electric motor, with varnish wire and slot cells and phases insulated with an aromatic polyamide paper, was operated in a glass enclosure at sequential operating temperatures (from 73° C (163° F) to 334° C (631° F)) in order to trap possible hydrogen cyanide and/or other volatile emissions generated under normal and overheat conditions.

(Over)

Abstract (Cont)

The total emission of hydrogen cyanide (669 micrograms) on heating would produce only 0.02 parts per million hydrogen cyanide concentration if this amount were released in a 1000 cubic-foot room. This is well below the threshold limit value, 10 parts per million, for hydrogen cyanide. Other outgassed products determined included benzene, toluene, ortho- and meta-xylene, aldehydes, nitrogen oxides, large quantitites of condensible lubricant vapors, carbon monoxide, and unidentified and odoriferous products. Some of these outgassed substances may be produced any time organic matter is pyrolyzed and in this case may originate from other organic materials used in the motor as well as the aromatic polyamide which constitutes 13 percent of the total combustible materials in the motor. Assuming again that the total amounts of each of these products were released into the atmosphere of a 1000 cubic-foot room, none of these constitutents, with the exception of total aldehydes, would exceed the threshold limit value. Total aldehydes reached the threshold limit value (2 parts per million) at 240° C (464° F) and exceeded it by a factor of 2.7 at 334° C (621° F). Production of offensive odors began at an operating temperature of about 240° C (464° F) and were intensified at 334° C (631° F); these may also add to the difficulty of working in the area.

(Authors)

ADMINISTRATIVE INFORMATION

This report pertains to an investigation of the outgassing characteristics of a 10-horsepower electric motor insulated with an aromatic polyamide paper. It is part of the Center's program to reduce toxic materials in submarine atmospheres, Task Area SR 0601, Task 0625, Element 611151N, Work Unit 2833-114, milestone 1.

LIST OF ABBREVIATIONS

TLV	= threshold limit value
p/m	= parts per million
a.c.	= alternating current
mm	= millimeter
l/min	= liter per minute
ml/min	= milliliter per minute
mg	= milligram
ft^3	= cubic foot
ml	= milliliter
cm^3	= cubic centimeter

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BACKGROUND

Currently, many nonmetallic materials used in submarines are synthetic polymeric products of various chemical compositions. Such materials, though they may possess many useful properties, must be viewed critically in terms of their potential effect on submarine air quality. The possible low heat resistance of some of these materials can result in solvent and additive outgassing and molecular degradation producing volatile toxic organic and inorganic products with or without impairment of their operational function.

Significant quantities of carbon monoxide and other highly toxic thermal degradation products have been detected upon thermal exposure of submarine materials in the past. The evolution of monomers, unreacted catalysts, stabilizers, solvents, or degradation products, many of which are toxic, may occur to some degree at relatively low temperatures and over long periods of time. All these factors and the knowledge that large quantities of these materials may be used in submarines indicate the need for critical screening prior to selection of materials for submarine applications.

A previous investigation of the effects of heat exposure on an aromatic polyamide paper, a material used in winding insulation of shipboard electric motors, has shown that significant quantities of hydrogen cyanide are evolve. Under certain conditions these can be three to four times the TLV, 10 p/m, at 750° F (399° C) and 41 to 63 times the TLV at 850° F (450° C).* This report relates to an investigation of outgassed constitutents from an electric motor with varnish wire and slot cells and phases insulated with an aromatic polyamide paper to determine whether intolerable quantities of hydrogen cyanide or other constituents are emitted when such a motor operates under normal or overheated conditions. Outgassing of other products such as hydrocarbons, aldehydes, and nitrogen oxides were also investigated.

EXPERIMENTAL PROCEDURES

APPARATUS

The motor used in this study was a 440-volt a.c., 3-phase, 10-horsepower induction motor with a size 215 stator frame having a 4-inch core length. It was rebuilt at this laboratory for this experiment. The motor was insulated in accordance with standard

*Abbreviations used in this text may be found on page i.

Navy requirements for class F operation (see appendix A). Insulating materials included Navy type ML wire; 97.60 grams of aromatic polyamide insulation; Navy approved insulating varnish; all additional materials for this motor are specified in the NAVSHIPS Technical Manual, chapter 9600.

The motor was bolted to a bench that had a stainless steel top. All necessary electrical and gas-sampling connections were made by drilling holes through the bench. The holes were then sealed with silastic 731 RTV adhesive/sealant (a silicone rubber, Dow-Corning) and time was allowed for the silastic to dry (75 hours). Thermocouples were installed in the stator winding. Operating temperatures of the motor were controlled by programmed reversal of the motor's turning direction until the selected operating temperature was reached. This temperature was then maintained by periodic reversal of motor direction. The motor was first run under normal operation for 3 hours to dissipate any residual volatiles. At the end of this run the motor temperature (stator winding) was 73° C (163° F).

An all glass cover (aquarium type tank 48 inches long, 18 inches wide, 22 inches high)* was placed over the motor. The rim of the glass tank was sealed to the stainless steel bench top with silastic which was allowed to dry (75 hours). The assembly was then leak tested. The complete assembly is shown in the drawing of figure 1 and photograph of figure .

As shown in figure 1, the gas-trapping system consisted of 1/4 inch stainless steel tubing, J, which originated inside the glass tank, went through the bench top, and was connected to a flowmeter, H, which served to indicate the circulation rate of the air through the assembly. The flowmeter was attached to the inlet of a trap submerged in liquid nitrogen in a Dewar jar, C. The outlet of the trap was connected to the inlet of a stainless steel Teflon diaphragm pump.** The outlet of the pump led through another piece of 1/4 inch stainless steel tubing, K, back to the glass tank. The temperature of the motor was monitored with two iron-constantan thermocouples. One thermocouple (not shown) was embedded in the end-turns of the stator where the copper leaves the iron and was connected to the temperature

*The tank is bound together with silicone rubber adhesive cured at 120° F for a few hours, M&L Aquatic, Baltimore, Maryland.

**Dia-Pump, G3, model 0880073, Air Control Incorporated, Norristown, Pennsylvania.

controller; the other, E, was embedded at the end of the end-turns of the stator and went to potentiometer E′. A third thermocouple, F, suspended inside the glass cover went to potentiometer F′, to monitor the air temperature in the tank. Gage D (mm Hg) was included to indicate any pressure change inside the tank.

A - INDUCTION MOTOR
B - AIR CIRCULATING PUMP
C - DEWAR JAR WITH LIQUID NITROGEN TRAP
D - PRESSURE GAGE (mm Hg)
E-E′ - THERMOCOUPLE & POTENTIOMETER, STATOR WINDING TEMPERATURE
F-F′ - THERMOCOUPLE & POTENTIOMETER FOR COVER AIR TEMPERATURE
G - GLASS COVER
H - FLOWMETER
I - MOTOR LEADS TO POWER
J - 1/4" SS TUBING OF TRAPPING SYSTEM, INTAKE
K - OUTLET
L-M- TRAP VALVES

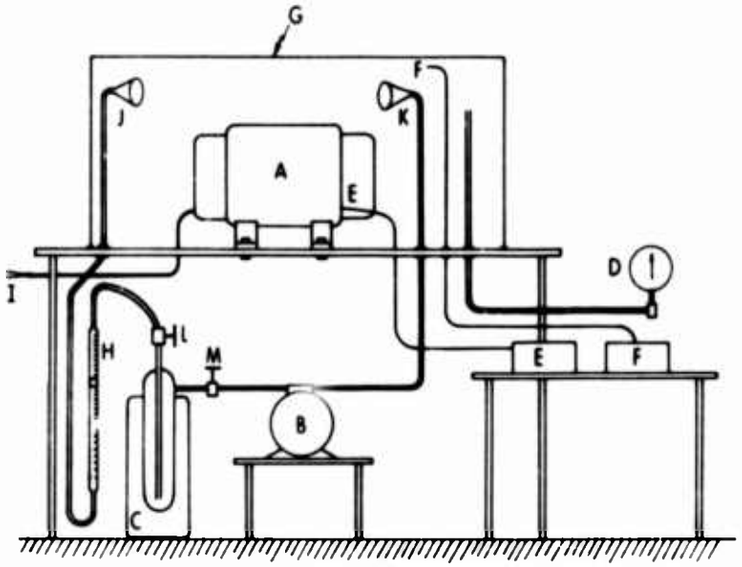

Figure 1
Electric Motor Outgassing
and Collection Assembly

OPERATING PROCEDURES

Motor-Stator-Reverse Cycling

This procedure was used to reach and sustain a desired temperature of the stator of the induction motor. The direction of motor rotation was reversed electrically (reversing the stator winding phase relationship) every 6 seconds until the stator winding reached the desired temperature. The motor was then operated without reversing until the stator winding cooled below

the desired temperature, whereupon reversing was resumed automatically until the desired temperature was restored. Thus, operation at the desired temperature was maintained.

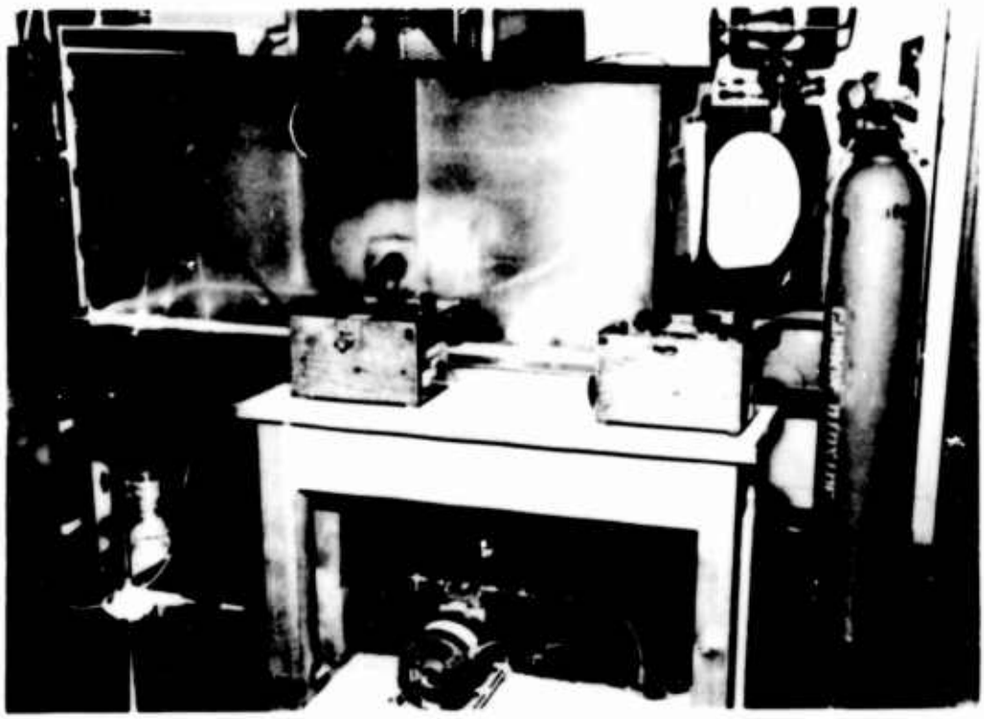

Figure 2
Electric Motor Outgassing
and Collection Assembly

Collection of Outgassed Products

The Dewar jar was filled with liquid nitrogen, the air circulating pump was turned on, and flows adjusted to circulate the air at 6 l/min. The test motor was then run under normal conditions (no reversing) for 3 hours. During this time the pump circulated the air inside the tank (about 208 liters) through the trap approximately five times or once every 35 minutes. At the end of this period the motor temperature (stator winding) reached 73° C (163° F), and the air in the tank reached 22° C (72° F). The motor and the pump were then turned off, the trap valves L and M (figure 1) closed, and the Dewar jar containing the trap with the trapped constituents was removed from the assembly. The outlet of the trap was attached to a Teflon sampling

bag (80-liter capacity) and the outlet valve, M, was opened to allow the contents of the trap to expand into the sampling bag as the trap was warmed to room temperature. Subsequently, the inlet of the trap was attached to a line of metered pure air, the inlet trap valve, L, opened, and a measured quantity of air allowed to enter the bag sweeping any volatiles from the trap into the bag. The gaseous bag contents, as well as any liquid remaining in the trap, were analyzed.

The reverse cycling technique was then used to increase the motor temperature to 140° C (284° F), 240° C (464° F), and 334° C (631° F).* The same collection and analysis procedures were followed.

ANALYTICAL METHODS

The following analytical methods were employed to analyze the trapped constituents:

- Carbon Monoxide. Determined by catalytic conversion of carbon monoxide to methane and measurement of methane with a gas chromatograph.[1]

- Total Hydrocarbons. Determined by gas-chromatography with flame ionization detector. A 12-foot stainless steel column packed with 10% UC-W98, 80/100s (Hewlett-Packard) was used, programming from 70° to 160° C at 4° per minute with 5-minute post injection and upper limit intervals. Nitrogen flow was 32 ml/min.

- Infrared Absorbtion Spectroscopy. Employed to detect functional groups of unexpected constituents.

- Oxides of Nitrogen. Determined by chemiluminescence with REM nitrogen oxides monitor, model 262.

- Total Aldehydes (As Formaldehyde). Determined by the MBTH** colorimetric method.[2]

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[1] Superscripts refer to similarly numbered entries in the Technical References at the end of the text.

*About one half hour required for the motor to reach the 140° C (280° F) temperature; for higher temperatures, approximately 1 hour was required.

**3-methyl - 2 - benzothiazolinone hydrazone hydrochloride.

- Hydrogen Cyanide. Determined by the chloramine-T method.[3]

Air drawn from the glass-tank at room temperature with the motor off was analyzed by the above methods to establish a blank. Since no cyanide or other constituents were detected, the blank was ignored. Further, to ascertain that emissions from the silicone rubber aquarium sealer* used in fabricating the tank and the silastic resin used to seal the tank have not contributed to the emissions from the motor, a one gram-sample from each of these resins which had been spread to a film, (about 1 mm thick) and cured at room temperature for 75 hours, was suspended inside a 500 cm^3 glass jar and heated in an oven sequentially at 120° and 250° F for 3-hour intervals. Gaseous samples drawn from each jar at each of these temperatures and analyzed by gas-chromatography showed negligible outgassing. This indicates that emissions from these resins have not contributed to the emissions from the motor.

RESULTS AND COMMENTS

The results of this study appear in table 1. The principal outgassed products were benzene, toluene, ortho- and meta-xylenes, aldehydes (expressed as formaldehyde), oxides of nitrogen, hydrogen cyanide, carbon monoxide, and condensible hydrocarbons. The calculations are additive in that all emitted constituents at 73° C (163° F) are included in the calculations for 140° C (284° F) and the quantities detected at 73° C (163° F) and 140° C (284° F) are included in the calculations for 240° C (464° F); all these again are included in the calculations for 334° C (631° F). These calculations were also converted to mg and p/m in a 1000 ft^3 volume.

Assuming that the total outgassed amounts of any of these products were released in a 1000 ft^3 room, only the total aldehydes would exceed the TLV (TLV for aldehydes, 2 p/m). At about 240° C (464° F) total aldehyde level approached 2.1 p/m and at 334° C (631° F), 5.4 p/m, the latter being greater than TLV by a factor of 2.7. Production of hydrogen cyanide, which was the main objective of this study, began with small amounts (21 mg) at about 240° C (464° F) and larger amounts (648 mg) at about 334° C (631° F), but the total (669 mg or 0.02 p/m in a 1000 ft^3 room) was far below the TLV (10 p/m).

*Dow Corning Corporation, Midland, Michigan.

TABLE 1
OUTGASSED CONSTITUTENTS FROM OPERATING
ELECTRIC MOTOR

Emitted Constituents µg	Motor Temperature, Sequential 73° C* 163° F	140° C** 284° F	240° C** 468° F	334° C** 631° F	Total Emission mg	p/m in a 1000 ft^3 38.32 m^3 Volume	TLV p/m
Benzene	-	40	1,088	1,423	1.42	0.0016	25
Toluene	52	344	8,669	12,639	12.64	0.12	100
o-xylene	145	697	29,596	24,416	42.42	0.34	100
m-xylene	66	431	9,601	14,868	14.87	0.12	100
Total aldehydes (as formaldehyde)	71	8,403	71,779	187,739	187.47	5.40	2
Nitrogen oxides	112	174	1,307	3,051	3.05	0.034	5
Hydrogen cyanide	None	None	21	669	0.67	0.021	10
Carbon monoxide	None	None	4,500	14,250	14.25	0.35	50

*Motor temperature under normal conditions.
**Motor temperature under overheat conditions.

Table 2 shows the motor temperature and the corresponding temperature of the air and pressure in the glass tank. It shows that even though the motor got very hot the air temperature inside the glass cover remained rather low and constant and, therefore, the pressure near atmospheric, a condition not too far from real situations. During the 240° C run, at approximately 200° C (392° F), smoke began to evolve from inside the motor while some oil began to run off onto the stainless steel bench top. When the temperature had stabilized at 240° C (464° F) heavy fog, some of which began to condense on the glass, was suspended inside the cover and the oil running off the motor increased. At the end of this run, motor temperature 240° C (464° F), 11.0 ml of water and 3.3 ml of an oily layer had been collected in the trap. Gas chromatographic analysis of this oil gave a typical multipeak gaschromatogram of heavy lubricating oils. During this run, the room air in the working area developed a strong unpleasant odor reminiscent of burned amine. This odor became very offensive during the later runs.

TABLE 2
ELECTRIC MOTOR TEMPERATURE AND CORRESPONDING
TANK AIR TEMPERATURE AND PRESSURE

	Motor Temperature, Sequential 75° C 163° F	140° C 284° F	240° C 464° F	334° C 631° F
Tank Air Temperature	22° C 102° F	57° C 201° F	94° C 201° F	117° C 243° F
Tank Pressure mm Hg	763	763	768	775

During the next run, motor temperature 334° C (631° F), more oil ran off the motor, and the condensation on the tank walls was greater. Figure 2 is a photograph of the complete assembly and shows the degree of condensation on the glass walls at the end of the run. When, upon completion of each of the runs, the motor was turned off and the tank cooled, the condensation on the glass walls of the tank (as well as the oil on the steel bench top) acquired a semisolid crystalline appearance.

It was intended to increase the motor temperature until the motor was completely destroyed or quit running; however, since the means to increase the speed of reversal (faster than six times per second, reverse cycling technique) were not available, the motor temperature could not be raised higher than 334° C (631° F). At the end of the 3-hour run at this temperature, the motor was still running but with a grinding noise indicating failing bearings. Upon completion of the experiment, the motor was taken apart and inspected. The bearing cavity was completely dry of grease and burned, and a jet black glassy coat covered the stator. Figure 3 is a photograph of the stator at this stage. Inspection of the crystalline deposit inside the tank showed that it was not homogeneous. It resembled a dry brown powdery material when it was scraped with a knife from areas near the motor and a dark waxy material from areas further away from the motor.

Figure 3
Disassembled Motor After 3-Hour
Operation at 334° C (631° F)

Gas-chromatographic analysis of the material from the stainless steel bench top gave the same peaks as the oil from the trap, indicating that the trap portion was made from condensed vapors of the run-off oil. The most prominent peaks in these chromatograms were those of benzene, toluene, and ortho- and meta-xylene, but no quantitative determinations were made. By infrared spectroscopic analysis the dry brown powder obtained from areas near the motor, where the temperature was highest, was identified as isophthalic acid; the dark brown waxy material was identified as highly oxidized silicone material. The bearing cavities of the motor had been packed, during construction, with approximately 24 grams (20 cm^3) of grease. Infrared analysis of this grease shows it to be a silicone lubricant containing an amine. The inside of the tank (approximately 23 ft^3) and the steep bench top were washed with acetone, to collect as much as possible of the organic deposit and the acetone evaporated. The residue (about 17 grams) was identified by infrared spectroscopy as the silicone lubricant used in the bearings of the motor but highly oxidized. The 334° C (631° F) experimental conditions represent an extreme situation which is not likely to be encountered during the normal life and operation of an electric motor.

CONCLUSIONS

- The results of this investigation indicate that operation of an overheated (up to 334° C (631° F)) electric motor with varnish wire and slot cells and phases insulated with the aromatic polyamide paper selected for this study, will not produce enough hydrogen cyanide to cause a health hazard.

- Amounts of aldehydes exceeding the TLV may be produced under prolonged extreme overheat (330° C (631° F)). Aldehydes may be produced any time organic matter is pyrolyzed and in this case may originate from other organic materials used in the motor as well as from the aromatic polyamide paper which constitutes 13% of all combustible materials in the motor.

- In confined spaces an overheated motor, such as the one studied, would release to the surrounding air large quantities of condensible vapors originating from the lubricant and would create difficult working conditions because of offensive odors.

RECOMMENDATION

It is recommended that a motor such as the one studied should not be operated at temperatures above 200° C (392° F).

TECHNICAL REFERENCES

1 - Porter, K., and D. H. Volman, "Flame Lonizatron Detection of Carbon Monoxide for Gas Chromatographic Analysis," Analytical Chemistry, Vol. 34, No. 7, pp. 748-9 (June 1962)

2 - Tentative Method of Analysis for Formaldehyde Content of Atmosphere (MBTH) Colorimetric Method - Application to Other Aldehydes, Vol. 7, No. 3, Health Library Service, Albany, N.Y., American Public Health Association Library Section (July 1970)

3 - Serfass, G. J., and R. F. Muraca, "Colorimetric Determination of Total and Free Cyandies," Plating, pp. 1027-30 (Aug 1956)

APPENDIX A

STATOR PREPARATION AND CONSTRUCTION

The stator cores were cleaned and the slots inspected for burrs. The stators included the following materials:

Magnet Wire*	No. 20 gage wire, heavy polyimide enamel (18 turns) (12 pounds, 5443 grams)
Slot Cell	Aromatic polyamide paper, 0.007 inch, 2 pieces (0.215 pound, 97.6 grams)
Phase	Aromatic polyamide paper, 0.007 inch, 1 piece (0.215 pound, 97.6 grams)
Coil Separator	Glass-silicone-glass laminate, 1/32 inch (2.42 ounces, 68.6 grams) 4% combusible
Wedge	Glass-silicone-glass laminate, 1/16 inch (3.05 ounces, 86.5 grams) 4% combustile
Tie Cord	Silicone-varnished glass cord (0.17 ounce, 4.33 grams) 17.2% combustile
Sleeving	Silicone rubber-coated glass (1.06 ounces, 30.5 grams) 20.4% combustile
Lead Wire	No. 12 silicone rubber-coated with glass braid armor (7 ounces, 198.5 grams) 10% combustible
Tape**	Glass with a thermo setting adhesive
Varnish	(15 ounces, 425 grams)
*Weight of conductor, 11.698 pounds (5306 grams); weight of polyimide enamel 0.302 pound (137 grams) **Weight of tape 0.33A ounce (9.46 grams); 25.3% combustile.	

The stators were connected in a single "Y" with six leads brought out so measurements could be made between phases.

During winding the following procedures were followed to ensure maximum environmental protection:

- The slot cells were cuffed.
- The slot cells were lap-folded over the top coil.
- The slot cells and wedges were extended 3/8 inch past the ends of the stator core.

DESCRIPTION OF VARNISH PROCESS

The stators were treated by applying three dips into the varnish and baked with the direction of dipping reversed for alternate dips; that is, leads up - first dip; leads down - second dip; and leads up - third dip. After dipping, the stators were air dried for 1 hour and then cured in an air circulating oven for 4 hours at 302° F for the first and second dips. After the third dip, the stators were air dried for 1 hour and then cured for 6 hours at 302° F.